DSMS Telecommunications Link
Design Handbook

103
34-m HEF Subnet
Telecommunications Interfaces

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Note to Readers

There are two sets of document histories in the 810-005 document, and these histories are reflected in the header at the top of the page. First, the entire document is periodically released as a revision when major changes affect a majority of the modules. For example, this module is part of 810-005, Revision E. Second, the individual modules also change, starting as an initial issue that has no revision letter. When a module is changed, a change letter is appended to the module number on the second line of the header and a summary of the changes is entered in the module's change log.

This module supersedes TCI-30 in 810-005, Rev. D.

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1 Introduction

1.1 Purpose

This module provides the performance parameters for the Deep Space Network (DSN) high-efficiency (HEF) 34-meter antennas that are necessary to perform the nominal design of a telecommunications link. It also summarizes the capabilities of these antennas for mission planning purposes and for comparison with other ground station antennas.

1.2 Scope

The scope of this module is limited to providing those parameters that characterize the RF performance of the 34-meter HEF antennas. The parameters do not include effects of weather, such as reduction of system gain and increase in system noise temperature, that are common to all antenna types. These are discussed in module 105, Atmospheric and

Environmental Effects. This module also does not discuss mechanical restrictions on antenna performance that are covered in module 302, Antenna Positioning.

2 General Information

The DSN 34-m Antenna Subnet contains three 34-meter diameter HEF antennas. These antennas employ an elevation over azimuth (AZ-EL) axis configuration, a single dual-frequency feedhorn, and a dual-shaped reflector design. One antenna (DSS 15) is located at Goldstone, California; one (DSS 45) near Canberra, Australia; and one (DSS 65) near Madrid, Spain. The precise station locations are shown in Module 301, Coverage and Geometry.

A block diagram of the 34-meter HEF microwave and transmitter equipment is shown in Figure 1. An orthomode junction for X-band is employed that permits simultaneous right-circular polarization (RCP) or left-circular polarization (LCP) operation. For listen-only operation or when transmitting and receiving on opposite polarizations, the low-noise path (orthomode upper arm) is used for reception. If the spacecraft receives and transmits simultaneously with the same polarization, the diplexed path must be used and the noise temperature is higher. The labyrinth used to extract the S-band signal from the feed also provides simultaneous RCP and LCP operation; however, the presence of only one S-band low noise amplifier (LNA) and receiver channel limits the use to selectable RCP or LCP.

In addition to spacecraft tracking, the DSN 34-m Antenna Subnet is also used for very-long baseline interferometry and radio-source catalog maintenance.

2.1 Telecommunications Parameters

The significant parameters of the 34-meter HEF antennas that influence telecommunications link design are listed in Tables 1 and 2. Variations in these parameters that are inherent in the design of the antennas are discussed below. Other factors that degrade link performance are discussed in modules 105 (Atmospheric and Environmental Effects) and 106 (Solar Corona and Wind Effects).

2.1.1 Antenna Gain Variation

The antenna gains in Tables 1 and 2 do not include the effect of atmospheric attenuation and should be regarded as vacuum gain at the specified reference point.

2.1.1.1 Frequency Effects

Antenna gains are specified at the indicated frequency (f_0). For operation at higher frequencies in the same band, the gain (dBi) must be increased by 20 log (f/f_0). For operation at lower frequencies in the same band, the gain must be reduced by 20 log (f/f_0).

2.1.1.2 Elevation Angle Effects

Structural deformation causes a reduction in gain whenever the antenna is operated at an elevation angle other than the angle where the reflector panels were aligned. The effective gain of the antenna is reduced also by atmospheric attenuation, which is a function of elevation. Figures 2 through 5 show the estimated gain versus elevation angle for the hypothetical vacuum condition (structural deformation only) and with 0%, 50%, and 90% weather conditions, designated as CD (cumulative distribution) = 0.00, 0.50, and 0.90. A CD of 0.00 (0%) means the minimum weather effect (exceeded 100% of the time). A CD of 90.0 (90%) means that effect which is exceeded only 10% of the time. Qualitatively, a CD of 0.00 corresponds to the driest condition of the atmosphere; a CD of 0.50 corresponds to humid or very light clouds; and 0.90 corresponds to very cloudy, but with no rain. A CD of 0.25 corresponds to average clear weather and often is used when comparing gains of different antennas. Comprehensive S-band and X-band weather-effects models (for weather conditions up to 99% cumulative distribution) are provided in module 105 for detailed design control table use. Equations and parameters for the curves in Figures 2 through 5 are provided in Appendix A.

2.1.1.3 Wind Loading

The gain reduction at X-band due to wind loading is listed in Table 3. The tabular data are for structural deformation only and presume that the antenna is maintained on-point by conical scan (CONSCAN, discussed in module 302) or an equivalent process. In addition to structural deformation, wind introduces a pointing error that is related to the antenna elevation angle, the angle between the antenna and the wind, and the wind speed. The effects of pointing error are discussed below. Cumulative probability distributions of wind velocity at Goldstone are given in module 105.

2.1.2 System Noise Temperature Variation

The operating system temperature (T_{op}) varies as a function of elevation angle due to changes in the path length through the atmosphere and ground noise received by the sidelobe pattern of the antenna. Figures 6 through 10 show the combined effects of these factors in a hypothetical vacuum (no atmosphere) condition and with the three weather conditions described above. The equations and parameters for these curves are provided in Appendix A of this module.

The system noise temperature values in Table 2 include a contribution due to 25% weather that must be subtracted for comparison with antennas that are specified without atmosphere (hypothetical vacuum). Table 4 provides adjustments to the 25% weather operating system temperature that were calculated using the weather models in module 105.

When two low-noise amplifiers (LNAs) are available for use, the amplifier in the lowest noise configuration is designated as LNA-1. Under some conditions, LNA-2 may be used, and the higher noise temperature values apply.

2.1.3 Pointing Accuracy

Figures 11 and 12 show the effects of pointing error on effective transmit and receive gain of the antenna. These curves are Gaussian approximations based on measured and predicted antenna beamwidths. Data have been normalized to eliminate elevation and wind-loading effects. The equations used to derive the curves are provided in Appendix A.

2.2 Recommended Minimum Operating Carrier Signal Levels

Table 5 provides the recommended minimum operating carrier-signal levels for selected values of receiver tracking-loop bandwidth (B_l). These levels provide a signal-to-noise ratio of 10 dB in the carrier-tracking loop, based on the nominal zenith system temperatures given in Table 2 and assuming 25% weather.

3 Proposed Capabilities

The following paragraph discusses capabilities that have not yet been implemented by the DSN but have adequate maturity to be considered for spacecraft mission and equipment design. Telecommunications engineers are advised that any capabilities discussed in this section cannot be committed to except by negotiation with the Telecommunications and Mission Operations Directorate (TMOD) Plans and Commitments Program Office.

3.1 S-Band LNA Enhancement

The existing S-band high-electron-mobility transistor (HEMT) LNAs at DSS 15 and DSS 45 and the cooled field-effect transistor (FET) LNA at DSS 65 are in the process of being replaced with HEMT amplifiers incorporating a cryogenically cooled input filter. The result will be a reduction in S-band system temperature (T_{op}) at all HEF stations to 26 ± 2 K near zenith, assuming a 25% average clear atmosphere.

Table 1. X-Band Transmit Characteristics

Parameter	Value	Remarks
ANTENNA		
Gain at 7145 MHz (dBi)	67.1 ±0.2	At gain set elevation angle, referenced to feedhorn aperture for matched polarization; no atmosphere included
Transmitter Waveguide Loss (dB)	0.25 ±0.05	20-kW transmitter output terminal (waterload switch) to feedhorn aperture
Half-Power Beamwidth (deg)	0.0777 ±0.004	Angular width (2-sided) between half-power points at specified frequency
Polarization	RCP or LCP	One polarization at a time, remotely selected
Ellipticity (dB)	1.0 (max)	Peak-to-peak axial ratio defined as the ratio of peak-to-trough received voltages with a rotating linearly polarized source and the feed configured as a circularly (elliptically) polarized receiving antenna
Pointing Loss (dB)		
Angular	See module 302	Also see Figure 12
CONSCAN	0.1	X-band CONSCAN reference set for 0.1 dB loss
EXCITER AND TRANSMITTER		
RF Power Output (dBm)	73.0, +0.0, –1.0	Referenced to 20-kW transmitter output terminal (waterload switch). Settability is limited to 0.25 dB by measurement equipment precision
Power output varies across the bandwidth and may be as much as 1 dB below nominal rating. Performance will also vary from tube to tube. Normal procedure is to run the tubes saturated, but unsaturated operation is also possible. The point at which saturation is achieved depends on drive power and beam voltage. The 20-kW tubes are normally saturated for power levels greater than 60 dBm (1 kW). Minimum power out of the 20-kW tubes is about 53 dBm (200 W). Efficiency of the tubes drops off rapidly below nominal rated output.		
EIRP (dBm)	139.9, +0.2, –1.0	

Table 1. X-Band Transmit Characteristics (Continued)

Parameter	Value	Remarks
EXCITER AND TRANSMITTER (Continued)		
Frequency Range Covered (MHz)	7145 to 7190	
Instantaneous 1-dB Bandwidth (MHz)	45	
Coherent with Deep Space S-Band D/L Allocation	7151.9–7177.3	240/749 turnaround ratio
Coherent with Deep Space S-Band D/L Allocation	7151.9–7188.9	880/749 turnaround ratio
Tunability (Hz)		At transmitter output frequency
Phase Continuous Tuning Range	2.0 MHz	
Maximum Tuning Rate	±12.1 kHz/s	
Frequency Error	0.012 Hz	Average over 100 ms with respect to frequency specified by predicts
Ramp Rate Error	0.001 Hz/s	Average over 4.5 s with respect to rate calculated from frequency predicts
Stability		At transmitter output frequency
Output Power Variation (dB)		Across frequency band over 12-h period
Saturated Drive	0.25	
Unsaturated Drive	≤1.0	
Group Delay Stability (ns)	≤1.0	Ranging modulation signal path over 12-h period (see module 203)
Frequency Stability		Allan deviation
1 s	3.3×10^{-13}	
10 s	5.2×10^{-14}	
1000–3600 s	3.1×10^{-15}	

Table 1. X-Band Transmit Characteristics (Continued)

Parameter	Value	Remarks
Spurious Output (dB)		Below carrier
1–10 Hz	–50	
10 Hz–1.5 MHz	–60	
1.5 MHz–8 MHz	–45	
2nd Harmonic	–75	
3rd, 4th & 5th Harmonics	–60	

Table 2. S- and X-Band Receive Characteristics

Parameter	Value	Remarks
ANTENNA		
Gain (dBi)		At gain set point (peak of gain versus elevation curve). See Figures 2–5 for elevation dependency. Tolerances have triangular PDF.
S-Band (2295 MHz)	56.0 ±0.25	Referenced to LNA input terminal (includes feedline loss) for matched polarization, no atmosphere included
X-Band (8420 MHz)	68.3 ±0.2	Referenced to maser LNA input terminal (includes feedline loss), non-diplexed (low noise) path, for matched polarization, no atmosphere included
	68.1 ±0.2	Referenced to maser LNA input terminal (includes feedline loss), diplexed path, for matched polarization, no atmosphere included
	68.2 ±0.2	Referenced to wideband HEMT input terminal (includes feedline loss), non-diplexed path, for matched polarization, no atmosphere included
	68.0 ±0.2	Referenced to wideband HEMT input terminal (includes feedline loss), diplexed path, for matched polarization, no atmosphere included

Table 2. S- and X-Band Receive Characteristics (Continued)

Parameter	Value	Remarks
ANTENNA (Continued)		
Half-Power Beamwidth (deg.)		Angular width (2-sided) between half-power points at specified frequency
S-Band	0.242 ±0.020	
X-Band	0.0660 ±0.004	
Polarization		Remotely selected
S-Band	RCP or LCP	
X-Band	RCP or LCP	Same or opposite from transmit polarization
Ellipticity (dB)	0.7	Peak-to-peak voltage axial ratio, RCP and LCP. See definition in Table 1.
S-Band	≤1.0	
X-Band	≤0.8	
Pointing Loss (dB, 3 sigma)		
Angular	See module 302	Also see Figures 11 and 12
CONSCAN		
S-Band	0.03	Loss at S-band when using X-band CONSCAN reference set for 0.1 dB loss at X-band
	0.1	Recommended value when using S-band CONSCAN reference
X-Band	0.1	Recommended value when using X-band CONSCAN reference
RECEIVER		
Frequency Ranges Covered (MHz))		
S-Band	2200–2300 MHz	
X-Band		
Telemetry	8400–8500 MHz	
VLBI	8200–8600 MHz	Wideband HEMT LNA

Table 2. S- and X-Band Receive Characteristics (Continued)

Parameter	Value	Remarks
RECEIVER (contd)		
Recommended Maximum Signal Power (dBm)	-90.0	At LNA input terminal
Recommended Minimum Signal Power (dBm)	See Table 5	
System Noise Temperature (K)		For average clear weather (25% weather condition) near zenith. See Figures 6–9 for elevation dependency. See Table 4 for adjustments to remove atmospheric contribution.
S-Band (2200–2300 MHz)	38.1 (DSS 15, 45) 44.1 (DSS 65)	With respect to LNA input terminal.
X-Band (8400–8600 MHz)		
DSS 15	19.8 ±2	With respect to maser input terminal, non-diplexed path.
DSS 45	20.2 ±2	
DSS 65	20.1 ±2	
DSS 15	28.9 ±2	With respect to maser input terminal, diplexed path.
DSS 45	29.3 ±2	
DSS 65	29.2 ±2	
DSS 15	44.8 ±2	With respect to wideband HEMT input terminal, diplexed path.
DSS 45	45.2 ±2	
DSS 65	45.1 ±2	
(8200–8600 MHz)		
DSS 15	35.7 ±2	With respect to wideband HEMT input terminal, non-diplexed path.
DSS 45	36.1 ±2	
DSS 65	36.0 ±2	
Carrier Tracking Loop Noise B/W (Hz)	0.25–200	Effective one-sided, noise-equivalent carrier loop bandwidth (B_L)

Table 3. Gain Reduction Due to Wind Loading, 34-m HEF Antennas

Wind Speed		X-Band Gain Reduction (dB)*
(km/hr)	(mph)	
16	10	0.2
48	30	0.3
72	45	0.4

* Assumes antenna is maintained on-point using CONSCAN or equivalent closed-loop pointing technique.
S-band gain reduction is negligible for wind speeds up to 72 km/hr (45 mph).
Worst case, with most adverse wind orientation.

Table 4. System Noise Temperature Contributions due to 25% Weather

Location	Noise Temperature Contribution (K)†	
	S-band	X-band
Goldstone (DSS 15)	1.929	2.292
Canberra (DSS 45)	2.109	2.654
Madrid (DSS 65)	2.031	2.545

† Calculated using weather model in module 105.

Table 5. Recommended Minimum Operating Carrier Signal Levels (dBm)†

Band, LNA, and Configuration	Receiver Effective Noise Bandwidth (B_L) (Hz)				
	0.25	1.0	2.0	20.0	200
S-Band LNA					
DSS 15 and DSS 45 (HEMT)	–178.8	–172.8	–169.8	–159.8	–149.8
DSS 65 (Cooled FET)	–178.2	–172.2	–169.1	–159.1	–149.1
X-Band Primary LNA (MASER)					
DSS 15 Non-Diplexed	–181.7	–175.6	–172.6	–162.6	–152.6
DSS 45 Non-Diplexed	–181.6	–175.5	–172.5	–162.5	–152.5
DSS 65 Non-Diplexed	–181.6	–175.6	–172.6	–162.6	–152.6
DSS 15 Diplexed	–180.0	–174.0	–171.0	–161.0	–151.0
DSS 45 Diplexed	–180.0	–173.9	–170.9	–160.9	–150.9
DSS 65 Diplexed	–180.0	–173.9	–170.9	–160.9	–150.9
X-Band Backup LNA (W/B HEMT)					
DSS 15 Non-Diplexed	–179.1	–173.1	–170.1	–160.1	–150.1
DSS 45 Non-Diplexed	–179.0	–173.0	–170.0	–160.0	–150.0
DSS 65 Non-Diplexed	–179.1	–173.0	–170.0	–160.0	–150.0
DSS 15 Diplexed	–178.1	–172.1	–169.1	–159.1	–149.1
DSS 45 Diplexed	–178.1	–172.0	–169.0	–159.0	–149.0
DSS 65 Diplexed	–178.1	–172.1	–169.0	–159.0	–149.0

† Levels are referenced to LNA input terminals with nominal zenith system noise including 25% weather.

* Bandwidths are centered about the received carrier.

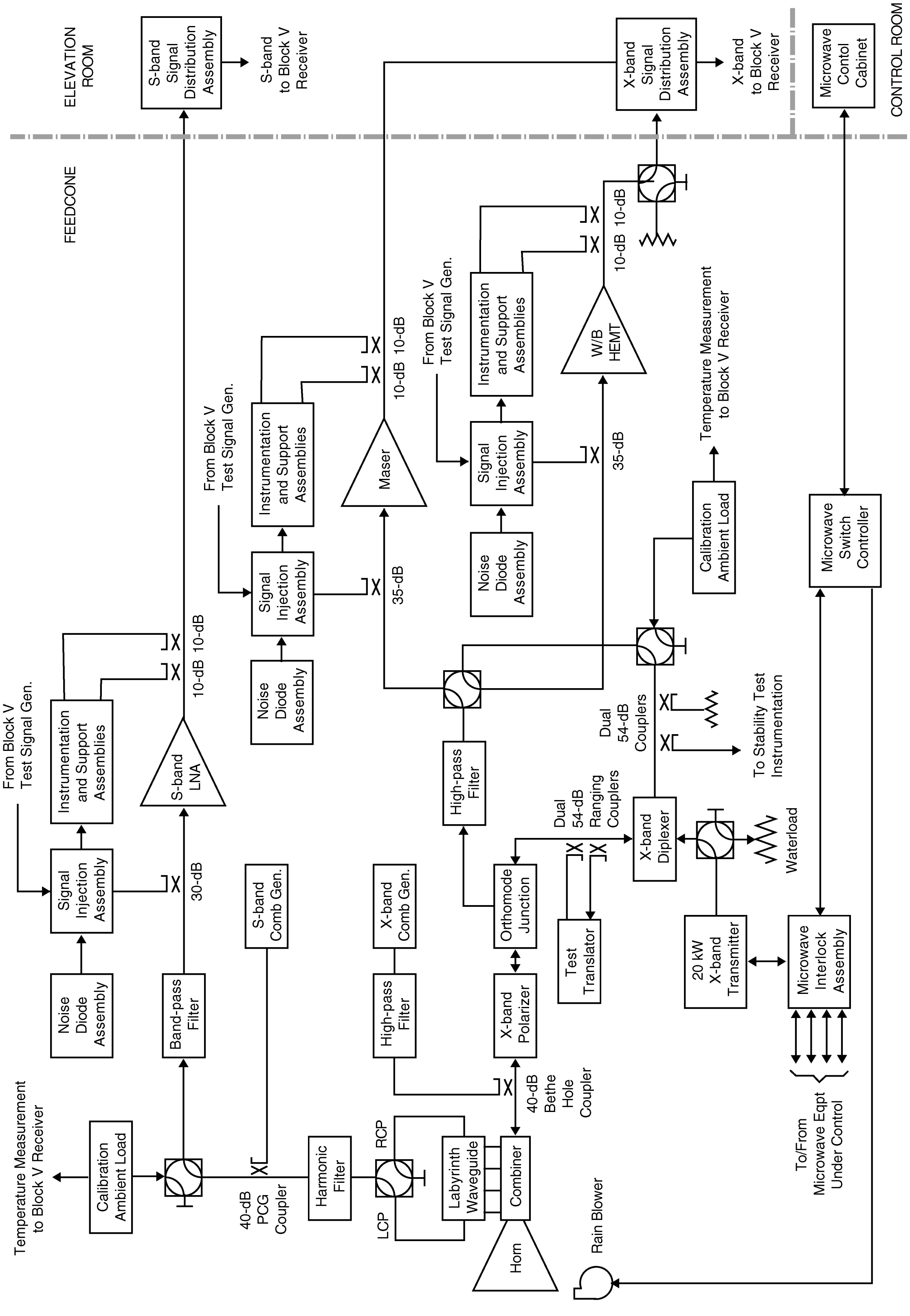

Figure 1. Functional Block Diagram of Microwave and Transmitter Subsystem

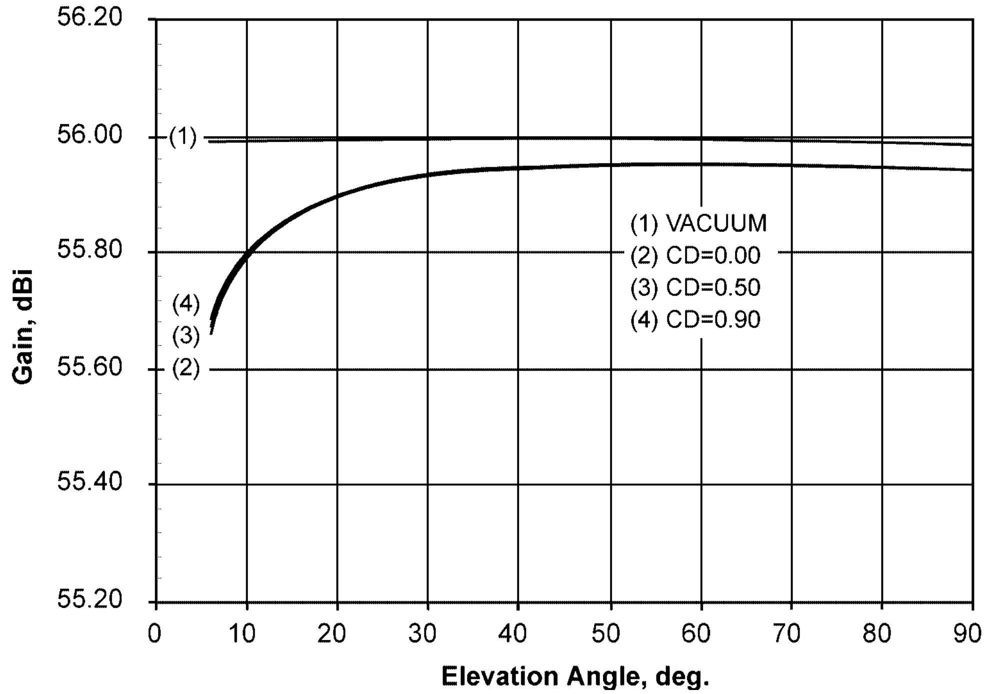

Figure 2. S-Band Receive Gain Versus Elevation Angle, All HEF Antennas

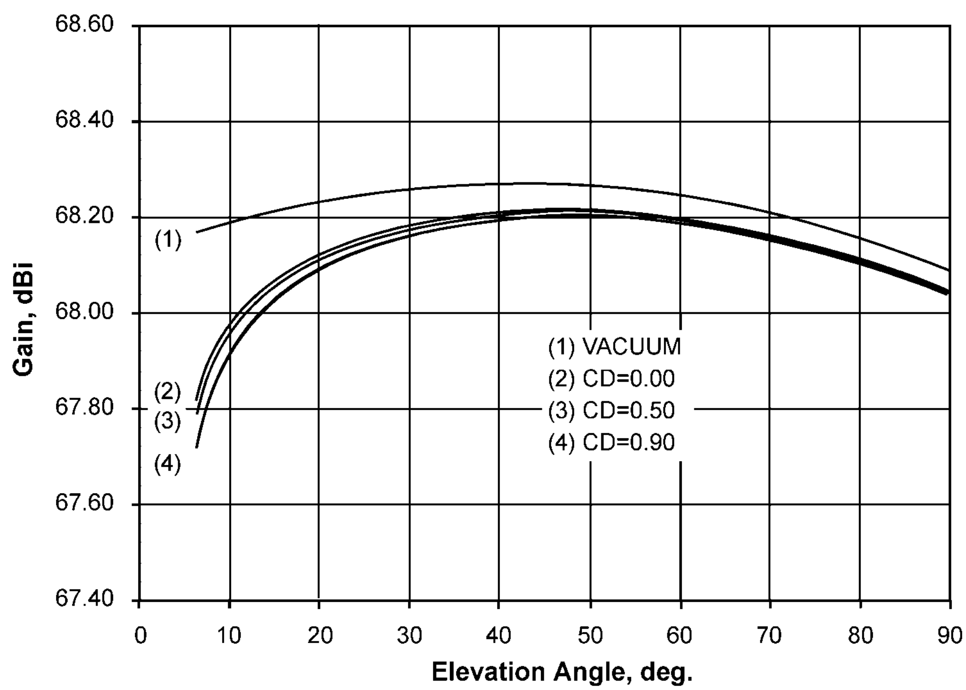

Figure 3. X-Band Receive Gain Versus Elevation Angle, DSS 15 Antenna, Non-Diplexed Path, Maser LNA Input

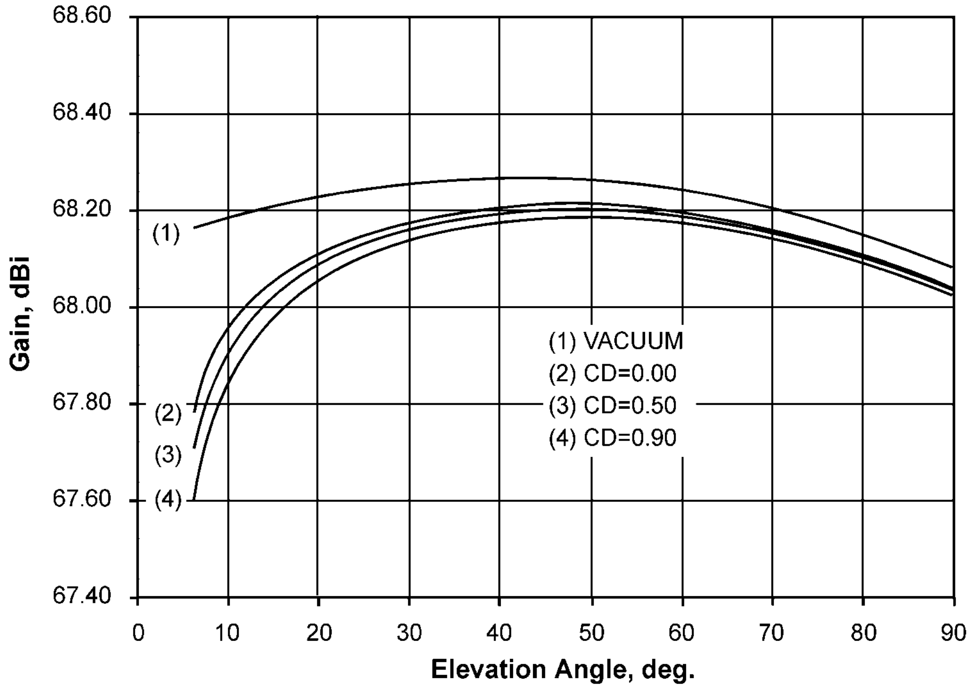

Figure 4. X-Band Receive Gain Versus Elevation Angle, DSS 45 Antenna, Non-Diplexed Path, Maser LNA Input

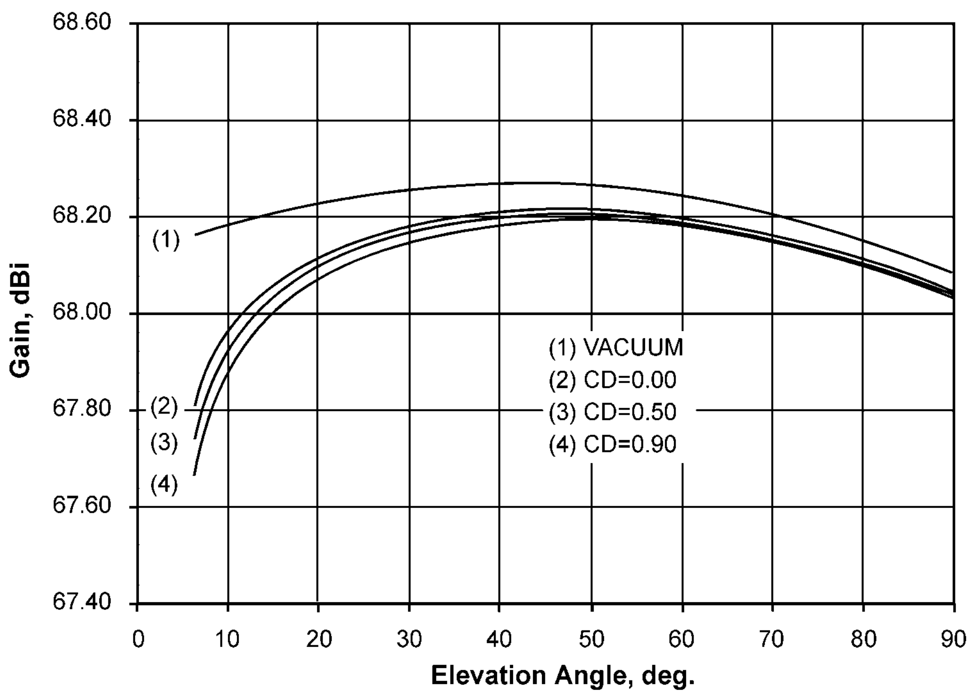

Figure 5. X-Band Receive Gain Versus Elevation Angle, DSS 65 Antenna, Non-Diplexed Path, Maser LNA Input

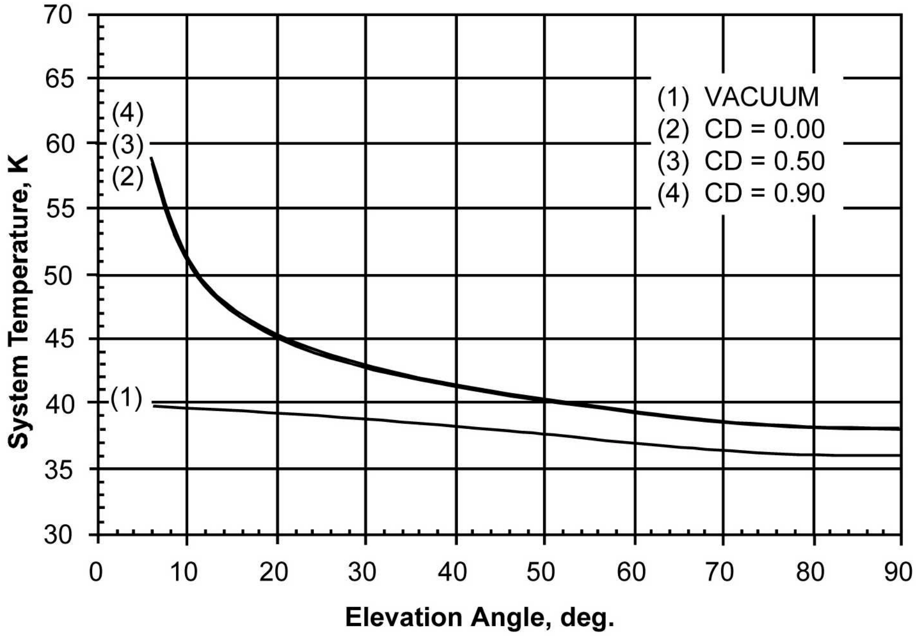

Figure 6. S-Band System Temperature Versus Elevation Angle, Average for DSS 15 and DSS 45 Antennas at LNA Input

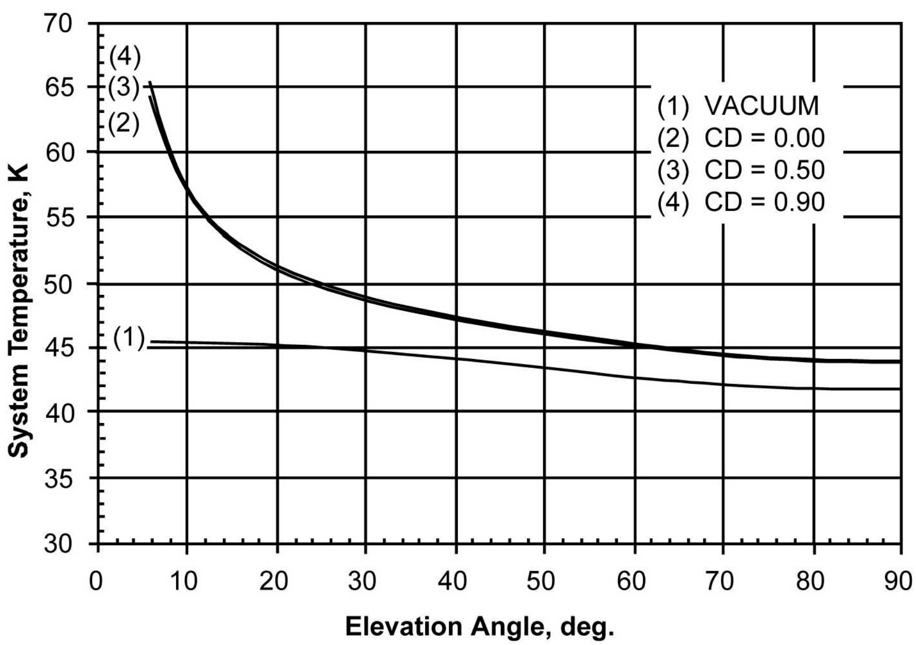

Figure 7. S-Band System Temperature Versus Elevation Angle, DSS 65 at LNA Input

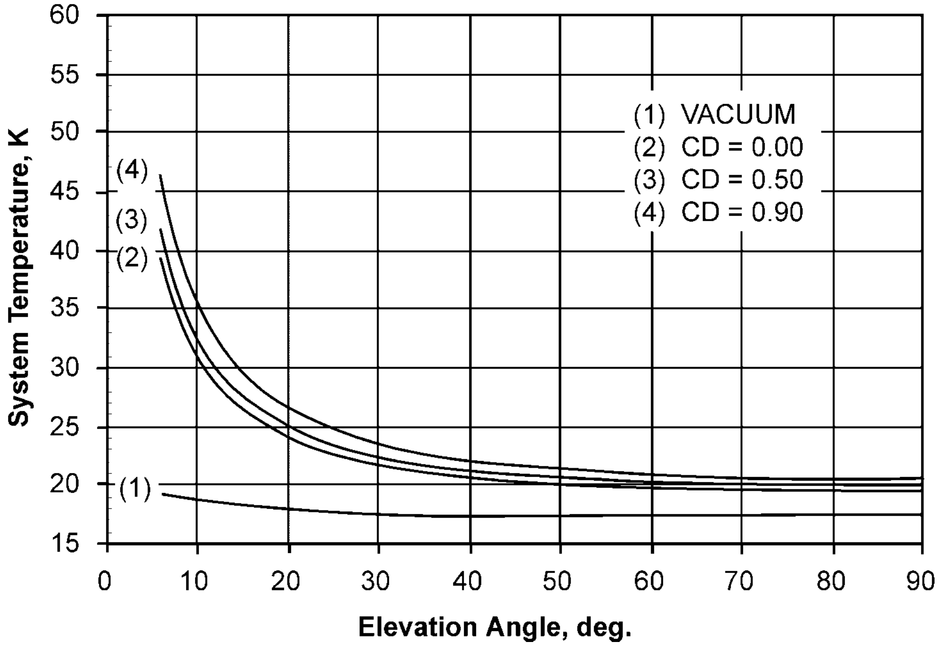

Figure 8. X-Band System Temperature Versus Elevation Angle, DSS 15 Antenna, Non-Diplexed Path, Maser LNA Input

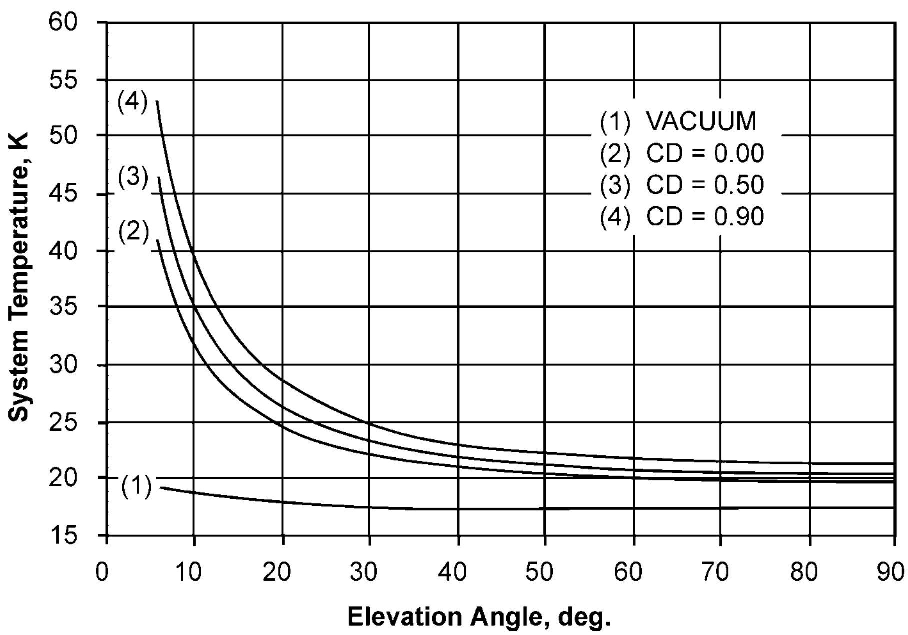

Figure 9. X-Band System Temperature Versus Elevation Angle, DSS 45 Antenna, Non-Diplexed Path, Maser LNA Input

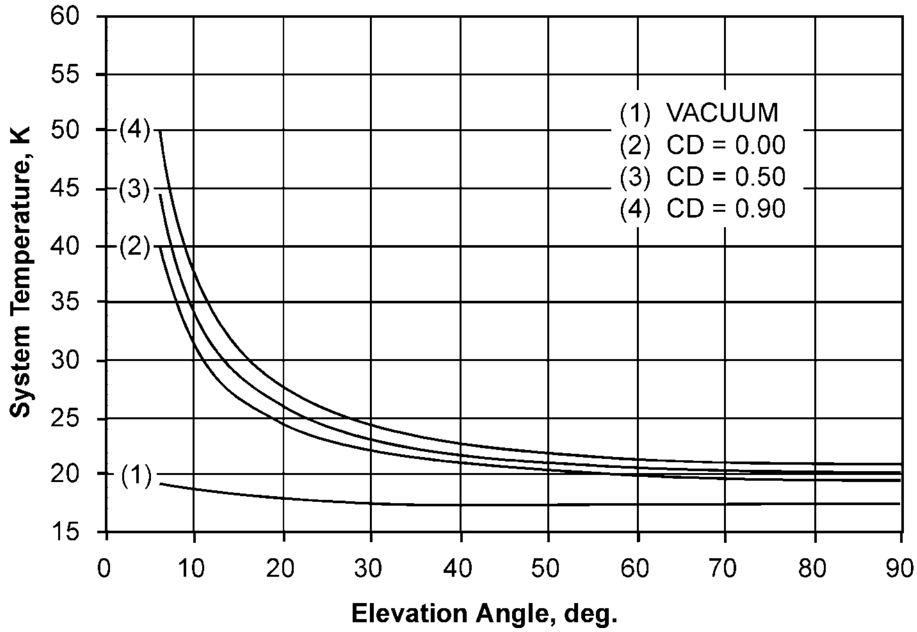

Figure 10. X-Band System Temperature Versus Elevation Angle, DSS 65 Antenna, Non-Diplexed Path, Maser LNA Input

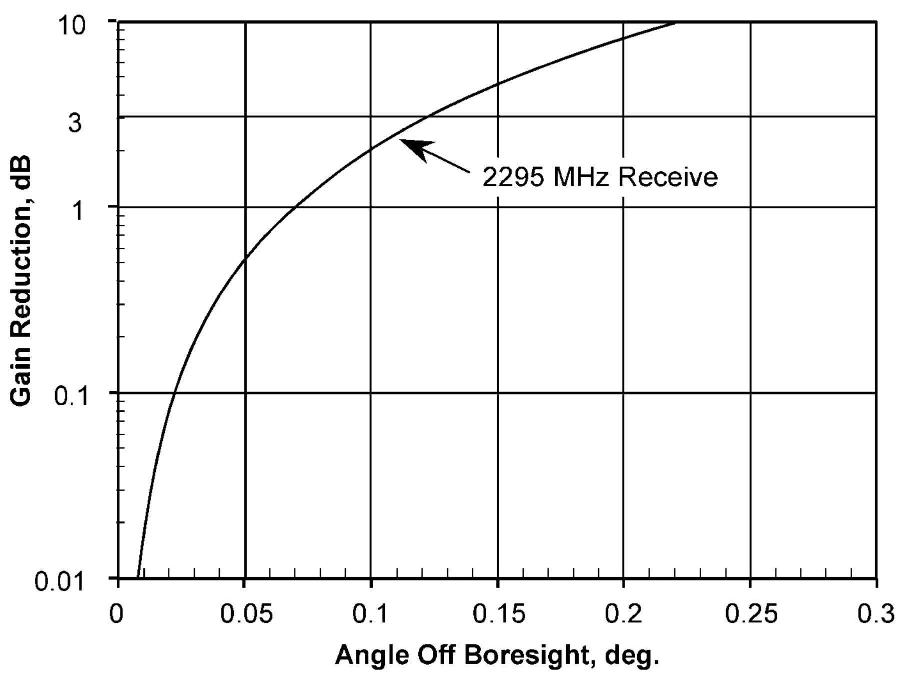

Figure 11. S-Band Gain Reduction Versus Angle Off Boresight

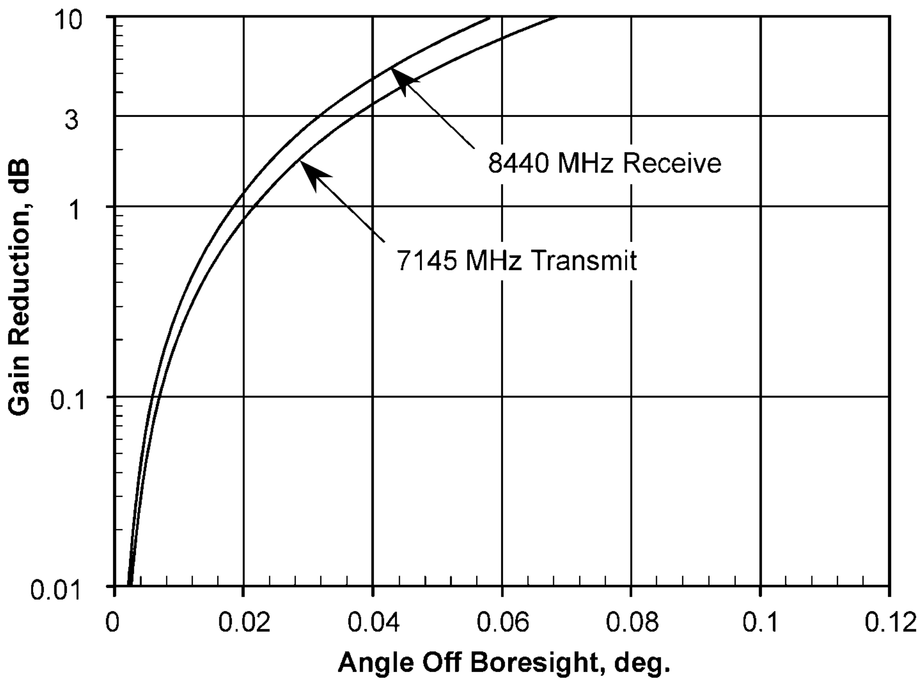

Figure 12. X-Band Gain Reduction Versus Angle Off Boresight

Appendix A
Equations for Modeling

A.1 Equation for Gain Versus Elevation Angle

The following equation can be used to generate S-band receive and X-band transmit and receive gain versus elevation angle curves. Examples of these curves are depicted in Figures 2–5. See paragraph 2.1.1.1 for frequency effect modeling and module 105 for atmospheric attenuation at weather conditions other than 0%, 50%, and 90% cumulative distribution.

$$G(\theta) = G_0 - G_1(\theta - \gamma)^2 - \frac{A_{ZEN}}{\sin\theta}\ ,\ \text{dBi} \tag{1}$$

where

θ	=	antenna elevation angle (deg.) $6 \le \theta \le 90$
$G_0, G_1, \ \gamma$	=	parameters from Table A-1
A_{ZEN}	=	zenith atmospheric attenuation from Table A-2 or from Table 2 in module 105, dB.

A.2 Equation for System Temperature Versus Elevation Angle

The following equation can be used to generate S- and X-band system temperature versus elevation angle curves. Examples of these curves are depicted in Figures 6–10. See module 105 for atmospheric attenuation at weather conditions other than 0%, 50%, and 90% cumulative distribution.

$$T_{op}(\theta) = T_1 + T_2 e^{\overline{\frac{-a}{(90.001-\theta)}}} + (255 + 25\,\text{CD})\left(1 - \frac{1}{10^{\frac{A_{ZEN}}{10\sin\theta}}}\right),\ \text{K} \tag{2}$$

where

θ	=	antenna elevation angle (deg.), $6 \le \theta \le 90$
T_1, T_2, a	=	parameters from Table A-3
CD	=	cumulative distribution used to select A_{ZEN} from Table A-2 or from Table 2 in module 105, $0 \le CD \le 0.99$
A_{ZEN}	=	zenith atmospheric attenuation for selected CD from Table A-2 or from Table 2 in module 105, dB.

A.3 Equation for Gain Reduction Versus Pointing Error

The following equation can be used to generate gain-reduction versus pointing error curves, examples of which are depicted in Figures 10 and 11.

$$\Delta G(\theta) = 10\log\left(e^{\frac{2.773\theta^2}{HPBW^2}}\right),\ \text{dB} \tag{3}$$

where

θ = pointing error (deg.)

$HPBW$ = half-power beamwidth in degrees (from Tables 1 or 2).

Table A-1. Vacuum Component of Gain Parameters

Configuration and Stations	Parameters†			
	G_0* (Transmit)	G_0* (Receive)	G_1	γ
S-band, All Stations (Figure 2)	—	56.00	0.000006	42.0
X-band, All Stations (Figures 3—5)	67.1	68.27	0.00008	42.0

Notes:

† G0 values are nominal at the frequency specified in Table 1 or Table 2. Other parameters apply to all frequencies within the same band.

* Favorable tolerance = +0.5 dB, adverse tolerance = –0.5 dB, with a triangular PDF.

Table A-2. S- and X-Band Zenith Atmosphere Attenuation Above Vacuum (A_{ZEN})

Weather Condition†	A_{ZEN}, dB*					
	S-band			X-band		
	DSS 15	DSS 45	DSS 65	DSS 15	DSS 45	DSS 65
Vacuum	0.000	0.000	0.000	0.000	0.000	0.000
CD = 0.00	0.033	0.036	0.034	0.037	0.040	0.038
CD = 0.50	0.032	0.035	0.033	0.040	0.048	0.045
CD = 0.90	0.031	0.034	0.033	0.047	0.059	0.053

Notes:
- * From Table 2 in module 105
- † CD = cumulative distribution.

Table A-3. Vacuum Component of System Noise Temperature Parameters

Configuration and Stations	Parameters		
	T_1*	T_2	a
S-Band, DSS 15 and DSS 45	36.1	8.063	63.45
S-Band, DSS 65	42.1	8.063	63.45
X-Band, All Stations, Maser Non-diplexed	17.55	1742	573.6
X-Band, All Stations, Maser Diplexed	26.65	1742	573.6
X-Band, All Stations, W/B HEMT, Non-diplexed	33.4.	1742	573.6
X-Band, All Stations, W/B HEMT, Diplexed	42.3	1742	573.6

Note:
- * Favorable tolerance = –2 K, adverse tolerance = +2 K, with a triangular PDF.